Social Network Analysis Research at AFIT

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Overview

- AFRL – NASIC – AFIT Partnership
- Overview of AFIT/ENS Focus
- Summary of Past Research
- 07M Thesis Research
- Conclusions
- Questions

AFRL/HE, NASIC/FCEB & AFIT/ENS Partnership

- AFIT/ENS and AFRL/HE have signed a MOA for behavioral modeling research in support of NASIC/FCEB for three years. November 06 marked the end of the second year of the effort.
  - Researchers gain access to cutting edge problems, subject matter experts, and data support
  - AFRL and NASIC benefit from research as it develops, aid in focusing work, and access to AFIT personnel and students
  - A win-win-win collaboration!
- This will be done through masters thesis and graduate research efforts and doctoral dissertations
- In addition, NASIC and AFIT have instituted a program to sponsor qualified officers and civilian personnel to attend AFIT

Perspectives

- Descriptive Models
  - **A model that attempts to describe the actual relationships and behavior of a system**
  - **The "what is" question**
  - **For a decision problem, such a model seeks to describe how individuals make decisions**

➢Provides insight

➢Perhaps create requirements

- Descriptive, Prescriptive and Predictive Models
  - **A model that attempts to describe the best or optimal solution of a system**
  - **The "what's best" & "what if" questions**
  - **For a decision problem, such a model is used as an aid in selecting the best alternative solution**

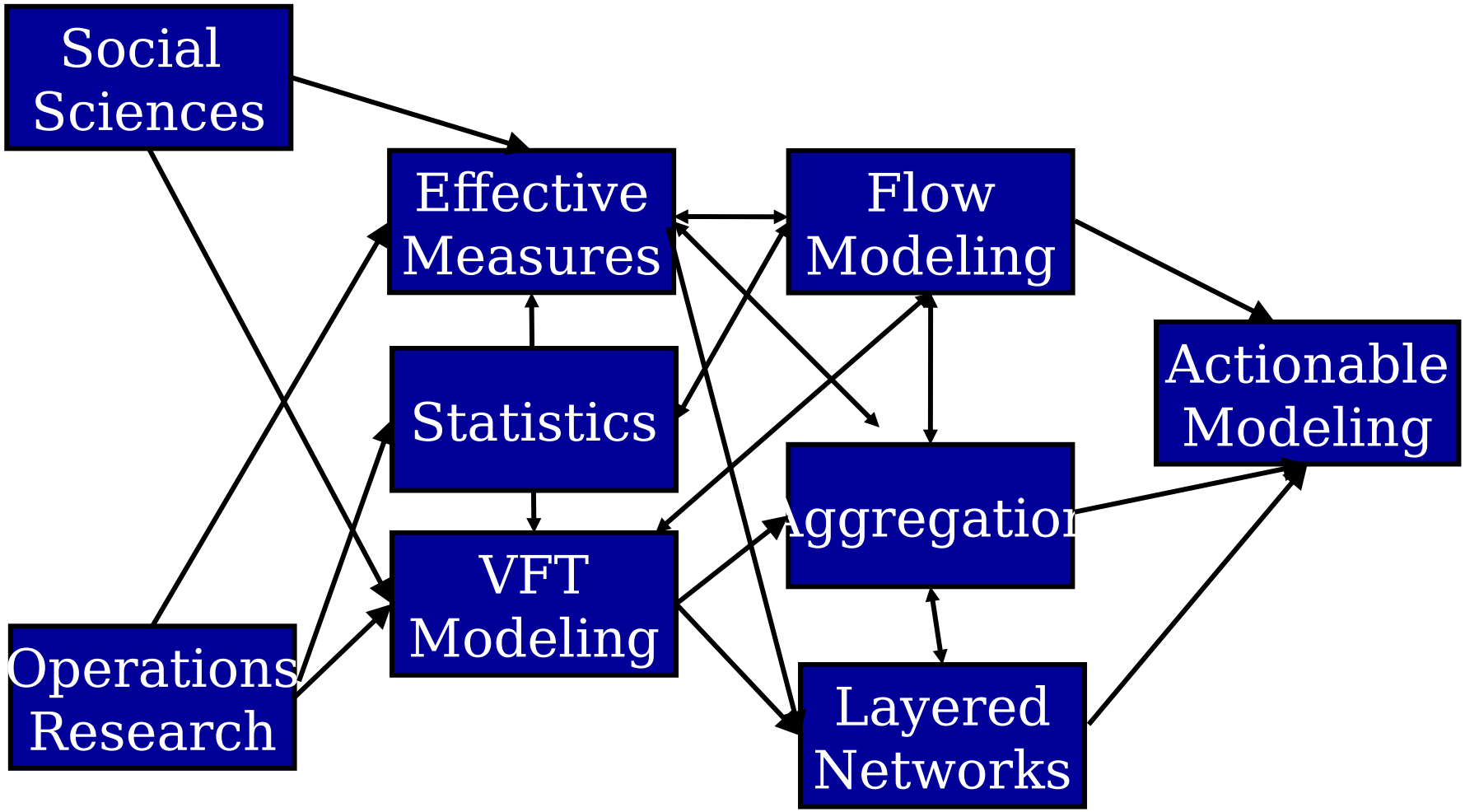
➢Provides insight

➢Perhaps create requirements

➢Actionable Options Evaluations

Models never perform analysis.
Analysts do analysis, aided by models where appropriate.

Overview of Plan



Some Early Behavioral Efforts

- ***Offensive PSYOP Value Hierarchy*** **, Lt Philip Kerchner, GOR 99M, sponsored by AIA/DO2 & JIOC**

- ***Malicious Hackers: A Framework for Analysis & Case Study*****, Captain Laura Kleen, GOR 01M, sponsored by DARPA**

- ***Modeling and Analysis of Social Networks,*** **Capt Rob Renfro, DSS-01S, sponsored by Intelligence Community Organization.**

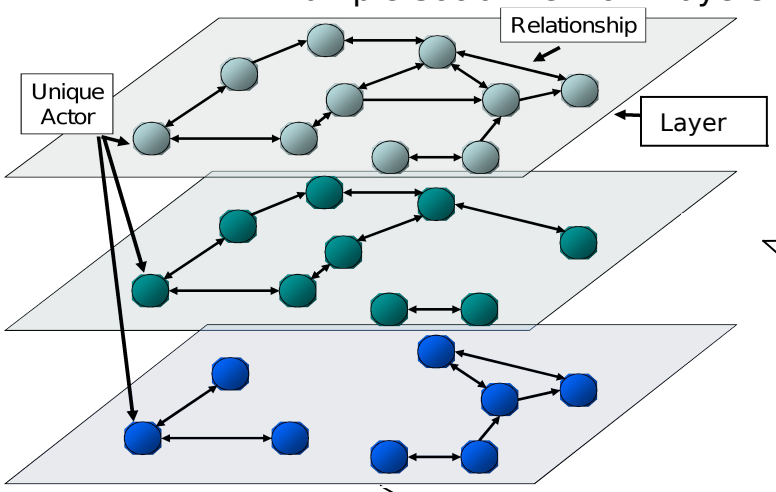
- ***Aggregation Techniques to Characterize Social Networks*** **Capt Sarah Sterling, GOR- 04M, sponsored by Intelligence Community Organization.**

05 Efforts

- ***Modeling and Analysis of Clandestine Networks,* Capt Clinton R. Clark GOR 05M,**
- ***Adaptation of A Decision Ladder Model to Behavioral Influences Analysis Intelligence Production Process*, Major Ty (Boomer) A. Chamberlain, GOS – 05E.** (Document is FOUO)
  - This research constructs a model of the intelligence production activities.
  - It can be used immediately to augment units Concepts of Operations (CONOPS) and Mission Overview.
  - The model provide insight to decision makers to make force structuring decisions, organize and structure analysts' activities, develop a training program for new analysts, or identify areas for future research.
- ***Influencing Transnational Terrorist Organizations: Using Influence Nets to Model Factor Weightings*, Major Roy (Frenchie) P. Fatur, GOS – 05E.**
  - This study consolidates an array of factors believed to influence the transnational terrorist
  - It suggests a framework for analyzing the interactions and relative importance of each factor to support resource allocation decisions.
  - A comprehensive literature review identified 13 factors having potential influence.

Clark Methodology Framework

Multiple Social Network Layers



Pair-wise Structural Influence

Determine Influence based on purely structural characteristics for *each* network layer

(Information Centrality)

Network Importance Weighting

Weight Networks

SNA Individual Centrality Measures

Individual Demographic data

ID	Name	Age	Tenure	Education	...
1	Agent1	26	8	HS	.
2	Agent2	69	16	MS	.
3	Agent2	35	10	PhD	.
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.

Discriminant Analysis

Determine Influence based on Personal Characteristics

(Posterior Probabilities)

Holistic Interpersonal Influence Measure

Matrix of pair-wise social influence based on individual and structural characteristics

Summary of Clark's Analysis Results

Analysis has demonstrated a broad spectrum of operational questions that could be supported

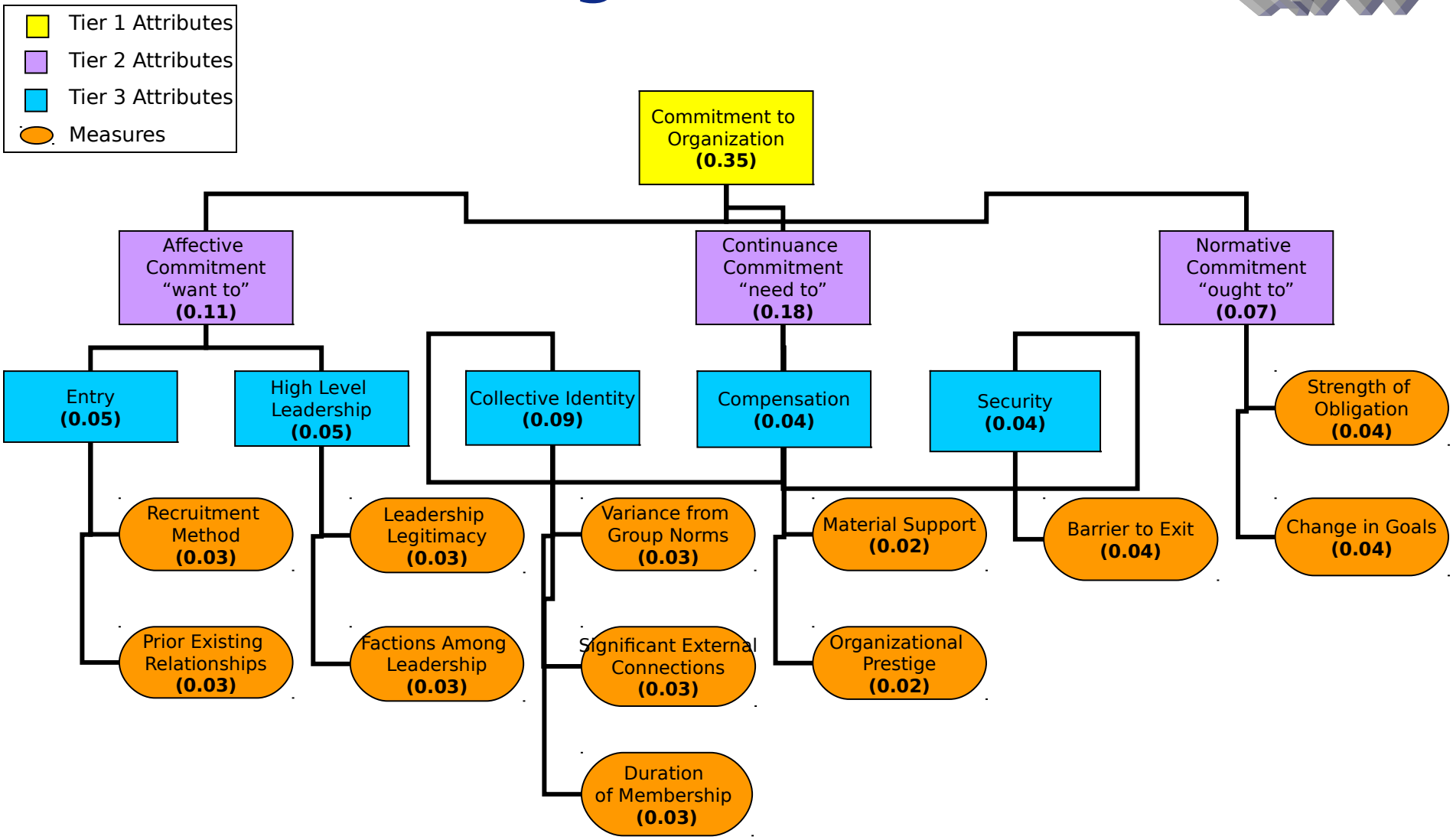
Technique	Enables
Discriminant Analysis	**Operational profiles;** **Classification rule (prediction);** **Measure of individual influence** **Validation of SNA Centrality Measures**
Information Centrality	**Measure of Interpersonal Influence based on network topology**
Linear Combination, Network Weighting	**Consideration of *each* informal network simultaneously**
Holistic Interpersonal Influence Measure (HIIM)	**Measure of interpersonal influence based on individual characteristics *and* network topology**
Network Flow (Maximum Flow)	**Identify members with greatest potential influence;** **Post optimality analysis; Alternate optimals**
Fuzzy Clique Analysis	**Identify core of subgroup;** **Identify members with influence over key subgroups;**

06 Efforts

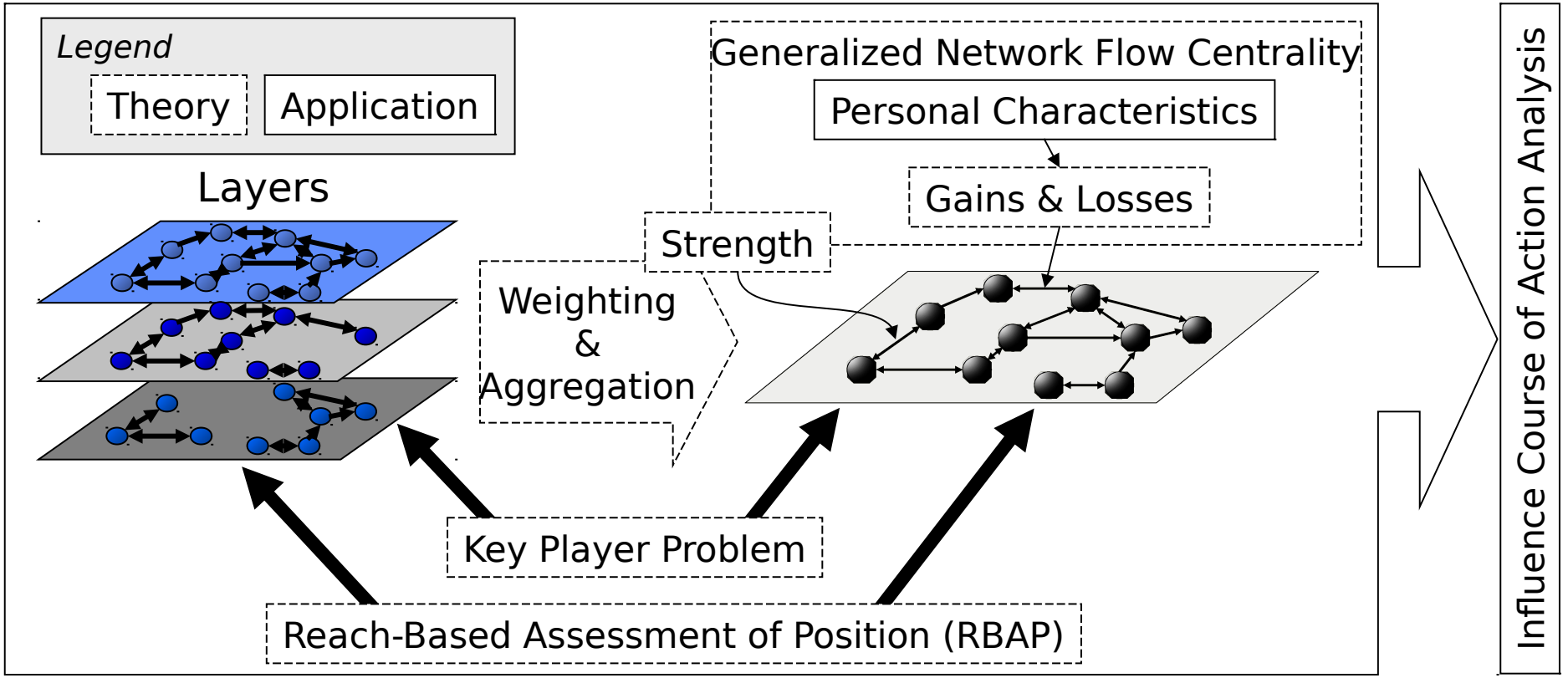
- *Gauging the Commitment of Clandestine Group Members* Lt Doneda Downs, GOR 06M

- *Analysis of Layered Social Network,* Maj J. Todd Hamill. DSS 06S

Downs Commitment to the Organization



Hamill Research Overview



Underlying Techniques:
Mathematical programming, decision analysis, graph theory, social network analysis

Hamill Contributions

- Methods dealing with multiplexity
  - Tie Strength
- Measurement of gains and losses
- New SNA Measures
  - RBAP
  - Generalized network flow centrality
- Multiple extensions of KPP-2
- Influence COA methodologies
- Accompanying MATLAB programs

07M Thesis Efforts

- *Examining Clandestine Social Networks for the Presence of Non-Random Structure,* Capt Joshua S Seder, GOR 07M.

- *Destabilizing Terrorist Networks and Operations,* Capt Jennifer L Geffre, GOR 07M.

- *Isolating Key Players in Clandestine Networks*, Capt Travis J. Herbranson, GOR 07M.

Examining Social Networks for Non-Random Structure

Research Objective

- **Knowledge of underlying edge structure can provide the analyst with answers to the following important questions:**
  - **What is the probability that any two actors are connected?**
  - **Is there evidence of local group memberships amongst the actors? If so, how do we explain this?**
- **<u>Problem</u>: edge structure not directly observable**
- **Develop a statistical framework for detecting, characterizing, and estimating non-random structure (in social networks) in the presence of noise**

Projected Operational Capability

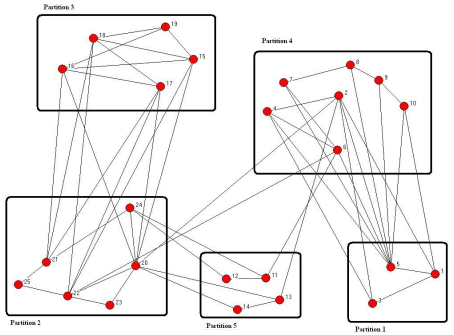
- **Tool application can provide valuable insight into "how" and "why" a network exists**
- **Can aid in the identification of underlying network vulnerabilities**
- **Provides efficient and objective estimates for the dyad probabilities**
- **Can be implemented to detect changes in structure over time**

Proposed Technical Approach

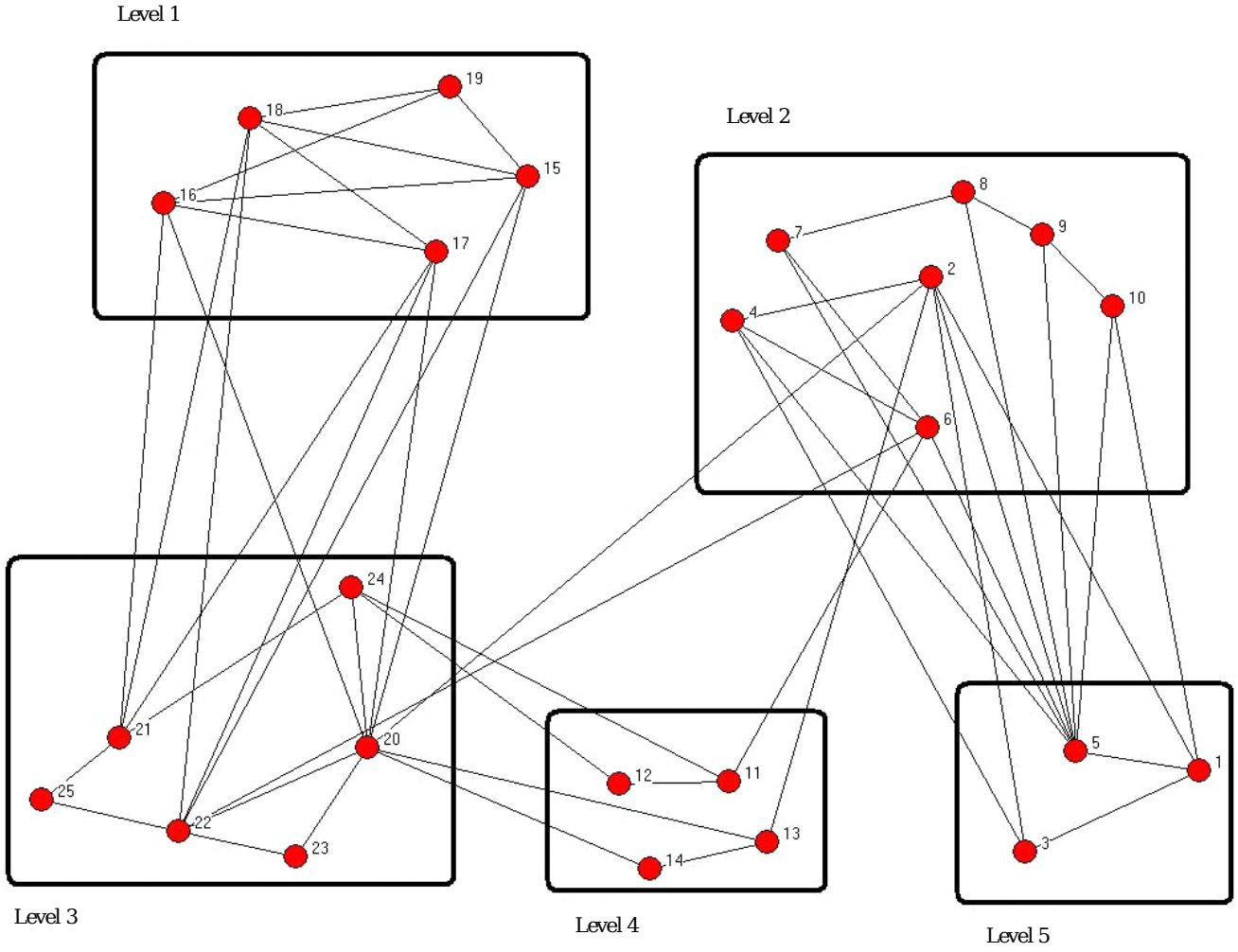
- **Statistical hypothesis testing framework**
- **Partition vertex set on the basis of exogenous actor attribute information**
- **Formulate likelihood ratio based on null and alternative hypotheses**
  - **Measures relative utility of partition in explaining variability in observed adjacency matrix**
- **Using observed adjacency matrix, estimate unknown parameters and compute test statistic (i.e. log-likelihood ratio statistic)**
- **Employ Monte Carlo simulation to aid in quantifying the significance level of the test**

Deliverables

- **Proposed methodology**
- **Thesis manuscript**



Methodology

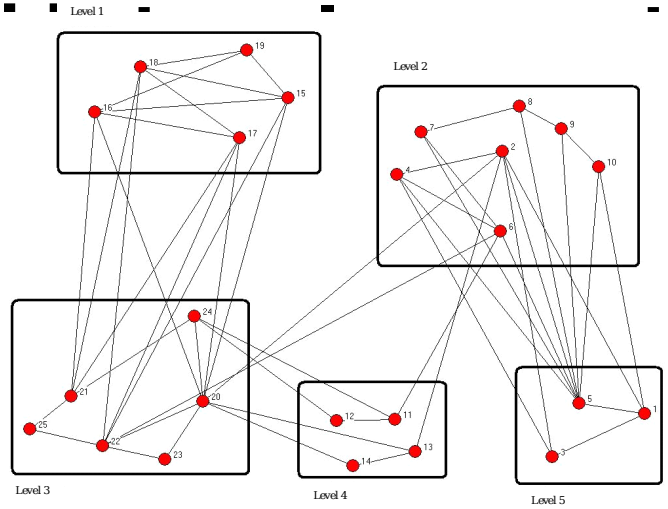


Methodology

- **Hypothesis test:**
  - H_0: $p_1 = \ldots = p_k = p_{12} = \ldots = p_{1k} = p_{2k} = \ldots = p_{k-1,k} = p_0$
  - H_a: $p_h \neq p_0$ U $p_{ij} \neq p_0$ for at least 1 h or i,j ($i < j$)
- H_0: postulates variability in observed adjacency matrix is unexplainable by the partition
- H_a: postulates variability in observed adjacency matrix is explainable by the partition
- Test statistic: log-likelihood ratio
  - Natural log of ratio of likelihood function specified under H_a to likelihood function specified under H_0
  - Statistic measures relative utility of partition in explaining variability in observed adjacency matrix
- Monte Carlo simulation used to quantify significance level of the test

Example

- First 100 actors listed in Sageman dataset
- Open source data on Al Qaeda terrorist network
- Apply to friendship ties
- 16 (2-level) partitions considered in analysis
- Overall experiment-w[illegible] of α=0.05



Example

- **Partitions based on:**

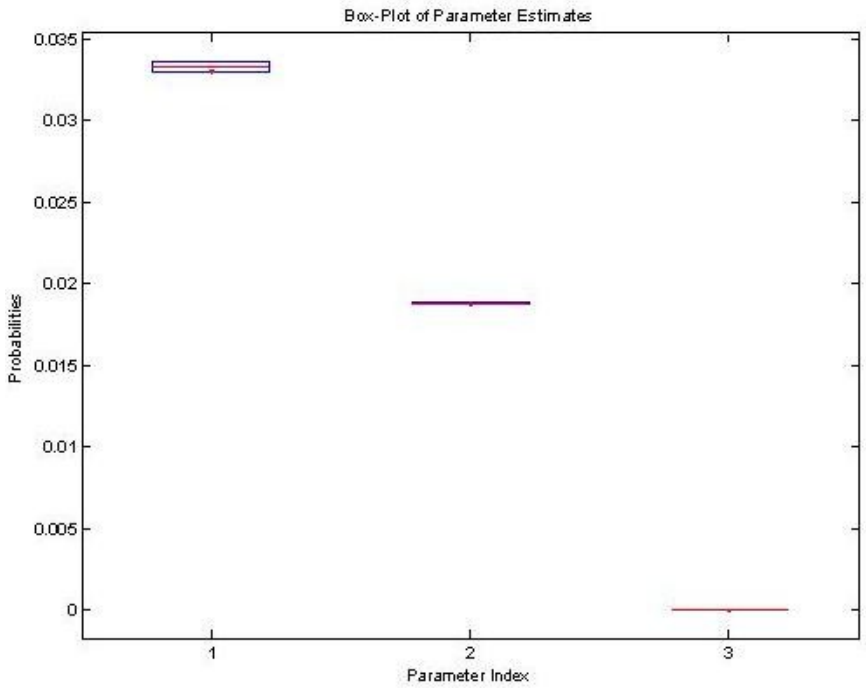
- **Date of birth**
- **Clump**
- **Marital status**
- **Children**
- **Place joined the Jihad**
- **Fate**
- **Age joined the Jihad**
- **Criminal background**
- **Year joined the Jihad**
- **Youth national status**
- **Family status**
- **Religious background**
- **Type of school attended**
- **Level of education**
- **Occupation**
- **Type of education**

Example

Attribute	$\hat{p}$-value	$\hat{F}$	$\hat{p}_1$	$\hat{p}_2$	$\hat{p}_{12}$	Weight
Age Joined	0.020	5.021	0.0108	0.0222	0.0085	0.0243
Clump	0.001	39.3741	0.0333	0.0188	0.0000	0.1902
Criminal Background	0.001	17.3311	0.0130	0.0553	0.0040	0.0837
Date of Birth	0.006	6.3059	0.0145	0.0204	0.0068	0.0305
Fate	0.006	6.6748	0.0301	0.0124	0.0075	0.0323
Kids	0.002	7.9796	0.0158	0.0216	0.0059	0.0386
Level of Ed	0.001	23.6071	0.0095	0.0238	0.0022	0.1141
Occupation Type	0.001	24.9879	0.0101	0.0236	0.0018	0.1207
Place Joined	0.001	9.8076	0.0160	0.0216	0.0035	0.0474
School Type	0.001	8.6639	0.0138	0.0000	0.0000	0.0419
Type of Ed	0.001	12.7106	0.0081	0.0293	0.0073	0.0614
Year Joined	0.001	36.858	0.0317	0.0187	0.0004	0.1781
Youth Nat'l Status	0.003	7.6422	0.0161	0.0170	0.0052	0.0369

Example

- **Maximum log-likelihood ratio achieved by partitioning actors by “Clump”**



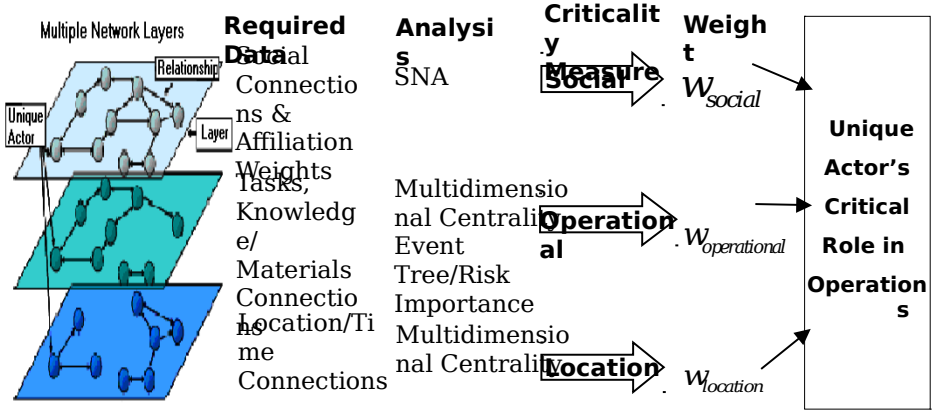
- **Partition: Clump**
  - **G1: Central Staff/SE Asian**
  - **G2: Arab/Maghreb Arab**
- **95% confidence bounds**
  - **Insight into “quality” of the parameter estimates**
- **Simple interpretation**
  - **Suggests identifiable structure present**

Future Research

- **Explore other forms of the alternative hypothesis**
- **Method for estimating input probabilities for Bayesian networks**
- **Extend method to consider a count of “event” occurrences between two vertices**
- **Develop algorithm for detecting and estimating changes in the structure over time**
- **Develop methods for estimating the time and magnitude of change in the structure**

A Layered Analysis of Clandestine Groups: Social, Resource and Operations Relations

Jennifer L. Geffre, Capt, USAF, GOR-07M, jennifer.geffre@afit.edu ~ Advisor: Dr. Deckro



Projected Operational Capability:

- Aims to identify critical members of networks based on social connections and contributions to operations through critical resources, tasks and knowledge.
  - Lower level (non-leader) individuals may be more critical to operations
  - Lower level individuals may be easier to influence or locate for removal
- Ultimate goal is to create an opportunity for the destabilization of operations and the potential for conducting attacks.

Technical Approach:

- Individual Criticality Score:
  - Social Criticality – Weighted Affiliation Layers & Centrality
  - Operational Criticality
    - Operations Task Importance – Reciprocal of Eigenvector Centrality
    - Operations Knowledge/Materials Importance - Event Tree and Risk Influence Measure
  - Temporal Local Importance by eigenvector centrality
  - Additive function with weights for layers

Model Attributes:

- Provides overall systematic methodology
- Collective Model – Multiple facets of network
  - Intermediate results also valuable
  - Final combined score for destabilization
- Draws on various analysis techniques
- Captures SME opinion
- However, potentially data intensive

Overview

- **Research Objective**
  - **Identify critical members of the network**
    - **Social Connections**
    - **Operational Contributions (Task, Resources and Knowledge)**
    - **Proximity to Locations of Importance**
  - **Use Suicide Bombings & Improvised Explosive Devices (IED)**

- **Model:**
  - **Utilizes techniques from various fields**
  - **Extends those techniques**
  - **Combines techniques into single model**
    - **Aids analysts with identifying potential options for destabilization**

Member Criticality

- **Preference ranking to destabilize network**
  - **Social Criticality –**
    - **Weighted affiliations between members**
    - **Eigenvector centrality**
  - **Operational Criticality**
    - **Task – Reciprocal of Eigenvector Centrality**
    - **Materials/Knowledge – Event Tree (probability of failure), Risk Importance Measures (reliability impact on operability)**
  - **Temporal Local – Multi-dimensional Centrality**
    - **Who met who, When & Where they met**
    - **Presence at location with no known meeting**
    - **Location Unknown**
  - **Preference Model – Weighted Additive Model**

Illustration of Method

- **US Embassies in Nairobi, Kenya and Dar es Salaam, Tanzania (August 7, 1998)**
  - **Group Responsible:**
    al-Qaeda's East Africa cell
  - **Explosive:**
    Ground TNT with aluminum powde
  - **Delivery:**
    Suicide vehicle borne IED (VBIED)

Illustration:
Strength of Relationships

Operational Network Affiliations

Affiliation	Ordinal Rank
Reverent Power	1
Traniner	1
Friend	3
Group Member	4

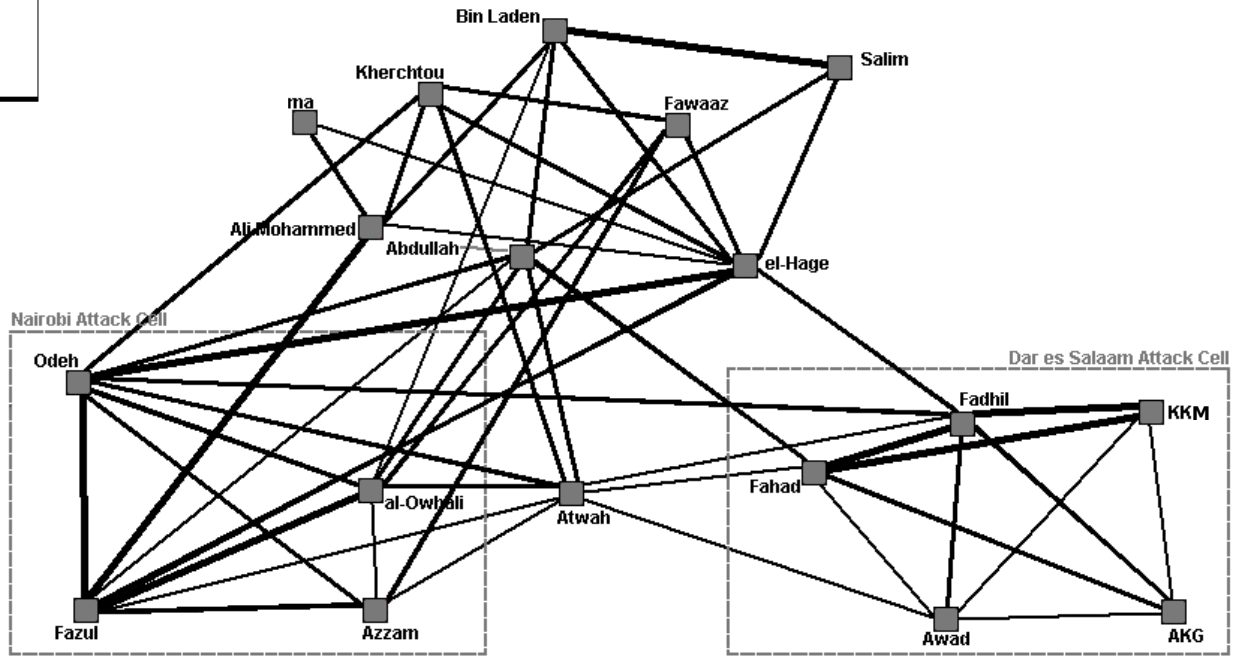


Illustration:
Social Criticality

Normalized Eigenvector Centrality

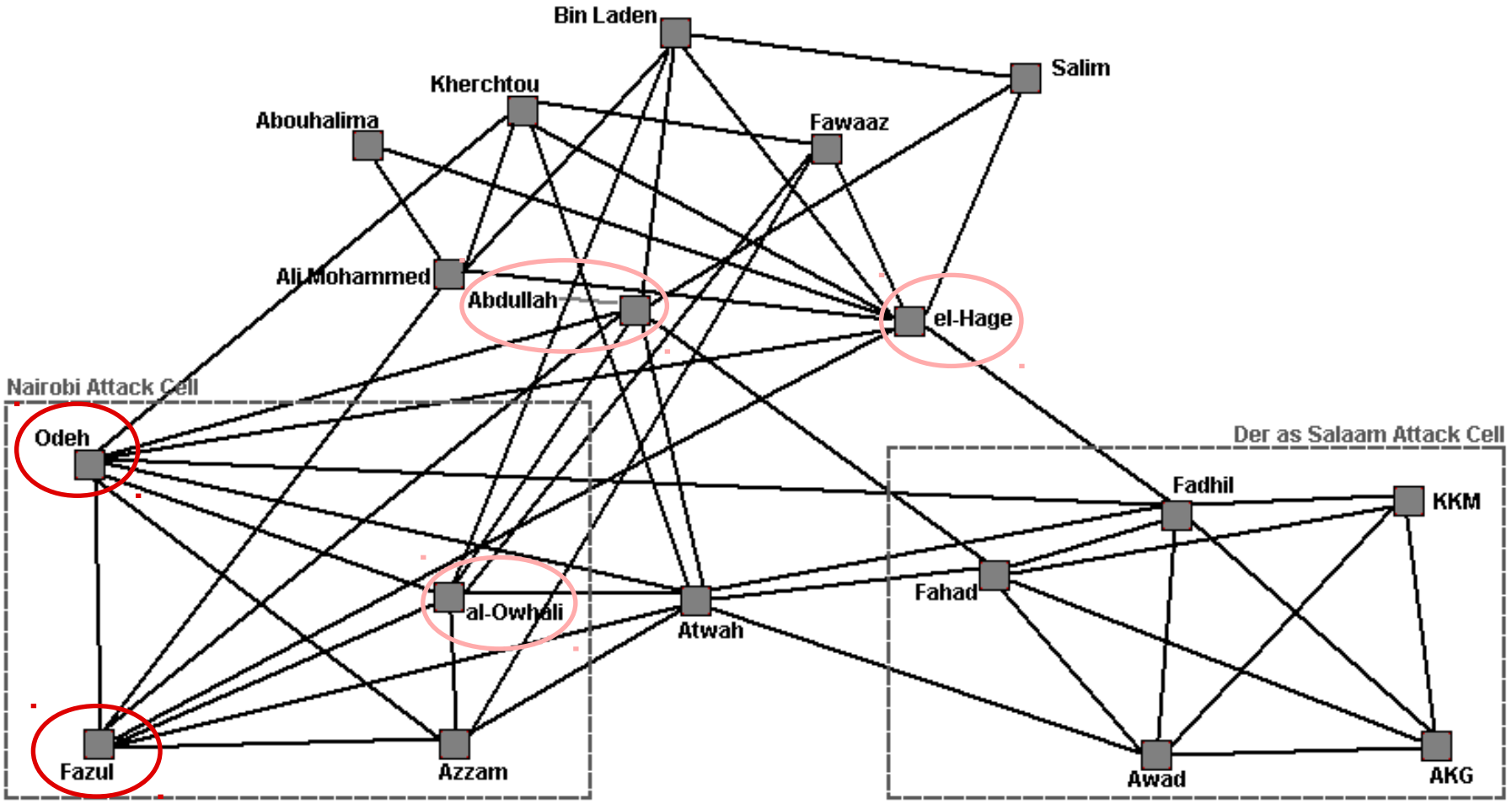


Illustration:
Operations Importance

- **Tasks –** Surveillance, Weapons Training, Driving, Bomb Preparations**, Bomb Assembly,** Bomb Detonation

- **Materials –** Funds**, Facility,** Truck**, Explosives**

- **Knowledge/Skills –** Weapons Expertise**, Electrical Engineer,** Surveillance, Suicide Bomber

Illustration:
Operational Criticality

Result based on task, materials & knowledge:

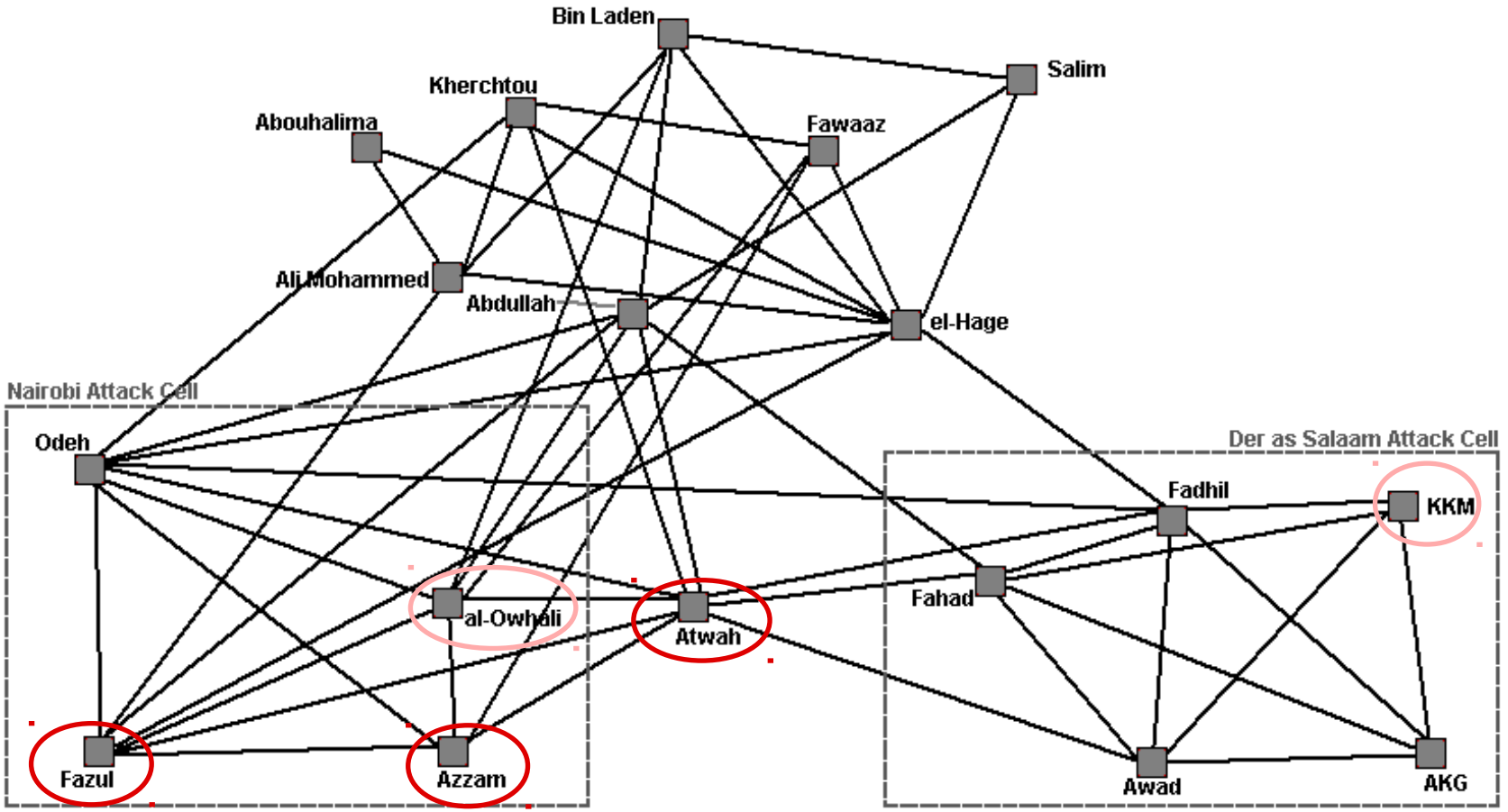


Illustration:
Locations of Interest

Based on observations – 12 Time & Locations

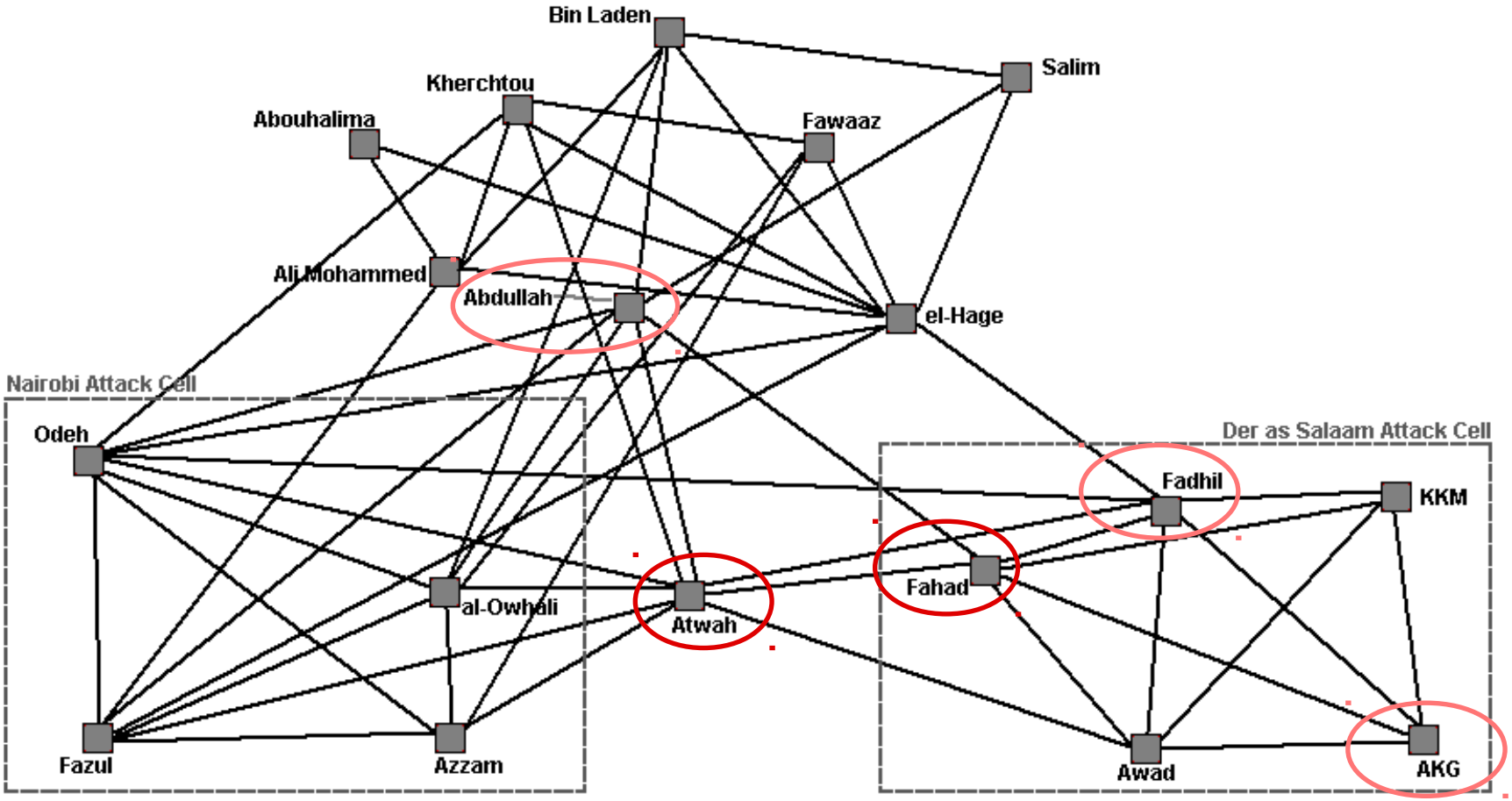
	Spring 1993	Summer 1997	Spring-Summer 1998	Late July - Early Aug	Attack
Osama Bin Laden	unk	unk	Pakistan	unk	unk
Mamdouh Salim	Khartoum, Sudan	Khartoum, Sudan	Bosnia	unk	unk
Ali Mohammed	Khartoum, Sudan	unk	unk	unk	unk
Wadih el-Hage	Khartoum, Sudan	Kenya	**unk**	United States	United States
Abdullah Ahmed Abdullah	Somalia	Kenya	**unk**	Kenya	Karachi, Pakistan
Khalid al-Fawwaz	Kenya	United Kingdom	United Kingdom	unk	unk
Muhsin Musa Matwalli Atwah	Somalia	**unk**	**unk**	Kenya, Tanzania	**unk**
Mohamed Sadeek Odeh	Somalia	Somalia	Kenya	Kenya	Karachi, Pakistan
Mohamed Rashed Daoud al-Owhali	unk	Kenya	Pakistan	Kenya	Kenya
Fazul Abdullah Mohammed	Somalia	Kenya	Sudan, Kenya	Kenya	Kenya
Azzam	unk	Kenya	Pakistan, Kenya	Kenya	Kenya
Fahad Mohammed Ally Msalam	unk	Kenya	Tanzania	Tanzania	Karachi, Pakistan
Mustafa Mohammed Fadhil	unk	unk	Tanzania	Tanzania	Karachi, Pakistan
Khalfan Khamis Mohamed	unk	unk	Tanzania	Tanzania	Tanzania
Ahmed Khalfan Ghailani	unk	unk	Tanzania	Tanzania	Karachi, Pakistan
Hamden Khalif Allah Awad	unk	unk	**unk**	Tanzania	Tanzania
Kherchtou	unk	unk	unk	unk	unk
Abouhalima	unk	unk	unk	unk	unk

6 2 4 1

unk 7

Illustration:
Location Criticality

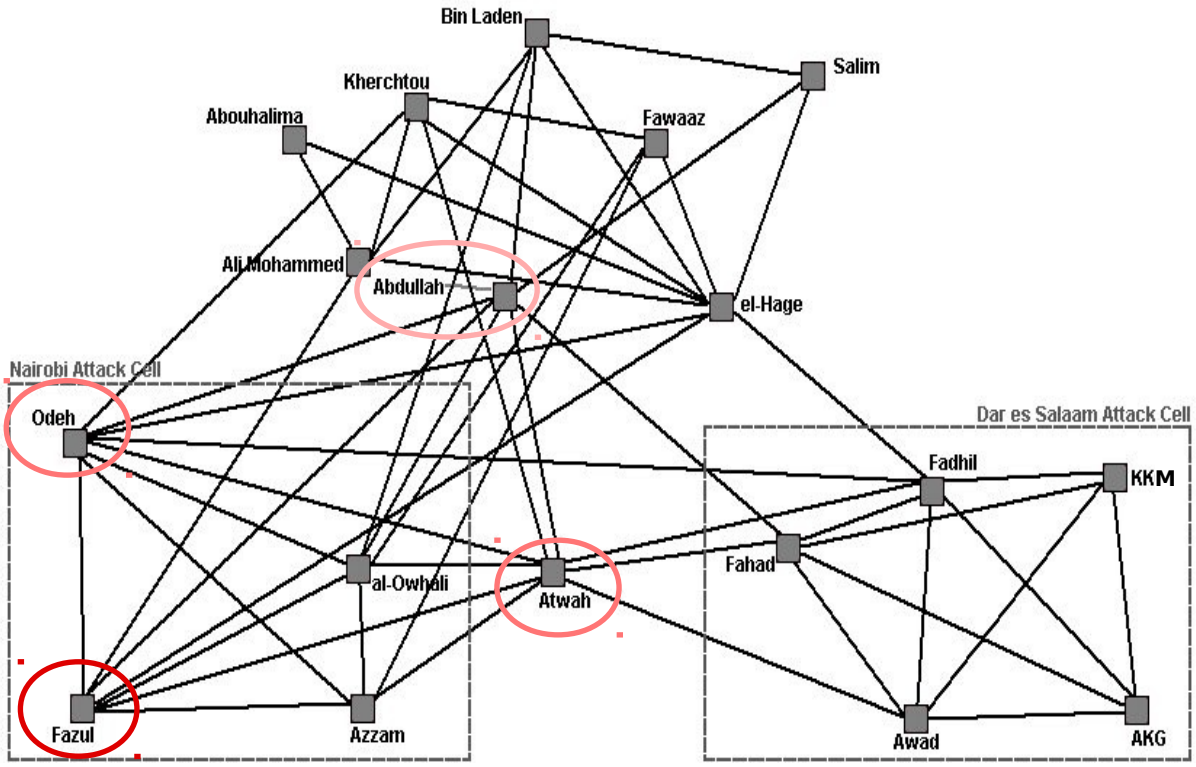
Results of Location Criticality



Destabilization Preference

Preference for influence or removal

Member	Preference Rank
Fazul Abdullah Mohammed	1
Mohamed Sadeek Odeh	2
Muhsin Musa Matwalli Atwah	3
Abdullah Ahmed Abdullah	4
Mohamed Rashed Daoud al-Owhali	5
Azzam	6
Wadih el-Hage	7
Mustafa Mohammed Fadhil	8
Khalfan Khamis Mohamed	9
Fahad Mohammed Ally Msalam	10
Ali Mohammed	11
Ahmed Khalfan Ghailani	12
Hamden Khalif Allah Awad	13
Mamdouh Salim	14
Osama Bin Laden	15
Kherchtou	16
Khalid al-Fawwaz	17
Abouhalima	18

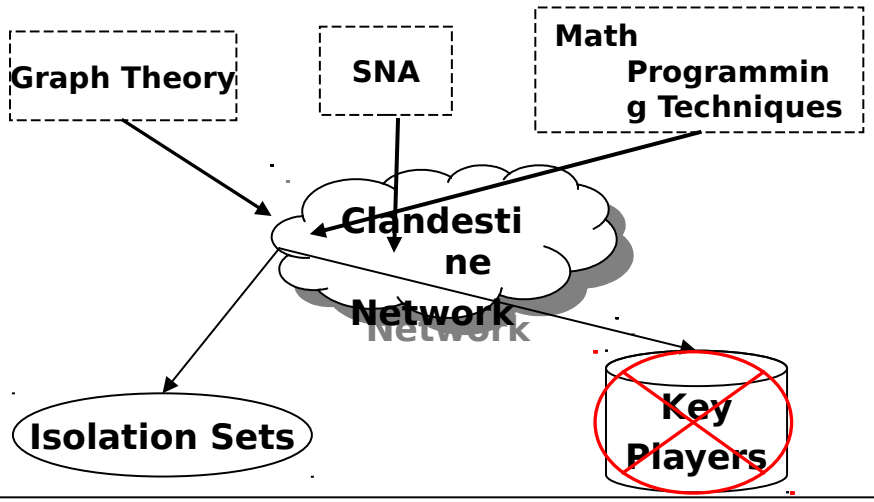


Summary

- **Provides overall systematic methodology**
- **Collective Model – Multiple facets of network**
  - **Intermediate results also valuable**
  - **Final combine score for destabilization**
- **Draws on various analysis techniques**
- **Captures SME opinion**
- **Can be extended to other operational settings**

ISOLATING KEY PLAYERS IN CLANDESTINE NETWORKS

Travis J Herbranson, Capt, USAF, GOR-07, travis.herbranson@afit.edu ~ Advisor: Dr. Deckro



Projected Operational Capability:

- Disruption targeting methods supporting the Global War on Terror
- A targeting method aimed at disrupting groups in a network by identify key arcs, with the ability to model real world limitations
- A targeting method to identify network member that play a key role in for all network connections
- A method to identify the network members, critical to a predefined group

Proposed Technical Approach: Continuing Effort

- Examination the mathematical programming knowledge of the isolation set problem
- Realistic approach to the isolation set problem, new model enhance the application
- A dynamic programming and integer programming approach to model the network key player problem
- Modeling a combined approach of the isolation set program and the network key player problem,

Deliverables

- Thesis
- New theoretical knowledge of the isolation set problem
- Software to find the optimal solution to the isolation set problem
  - Provides interface to a mathematical solver using a math programming set language
- New optimal seeking techniques to solve the network key player problem with respect to structure
- Support software to solve and display the optimal network key player problem
  - Modules to analyze the optimal solutions to determine the 'important' nodes in the network.

Overview

- **Research Objective**
  - **Disrupt networks to prevent them maintaining operational efficiency and effectiveness**
  - **Identify critical connections of the network**
  - **Identify critical members of the network**

- **Model:**
  - **Isolation set problem**
    - **Problem extended to real world applications**
  - **Key player problem**
    - **Mathematical programming models with provably optimal solutions**

ISP Model

- **Isolation Set Problem (ISP), Bennington, Bellmore, and Lubore (1970)**

- **<u>Model Input</u>: Groups in a network, the connections between the groups, and the strength of the connections**

- **<u>Model Output</u>: The least cost method to separate the groups, identified in the model input**

- **<u>The solution</u>: the disruption target set D of arcs or nodes**
  - **Removing the arcs or nodes from the network, separates the groups.**

Extensions to KPP1 Model

- **Key Player 1 (KPP1) Model, Borgatti (2003)**
  - **The set of nodes such that when removed from network causes maximum disruption**
  - **The disruption effect of KPP1 maximizes the shortest path distance between all remaining nodes**
- **Extensions**
  - **Formulated and solved mathematical program to optimality of KPP1**
  - **Reformulated KPP1 to be more operational as KPP3**
    - **Developed heuristic for quick turn solutions of larger networks**
    - **Formulated and solved mathematical program to optimality**

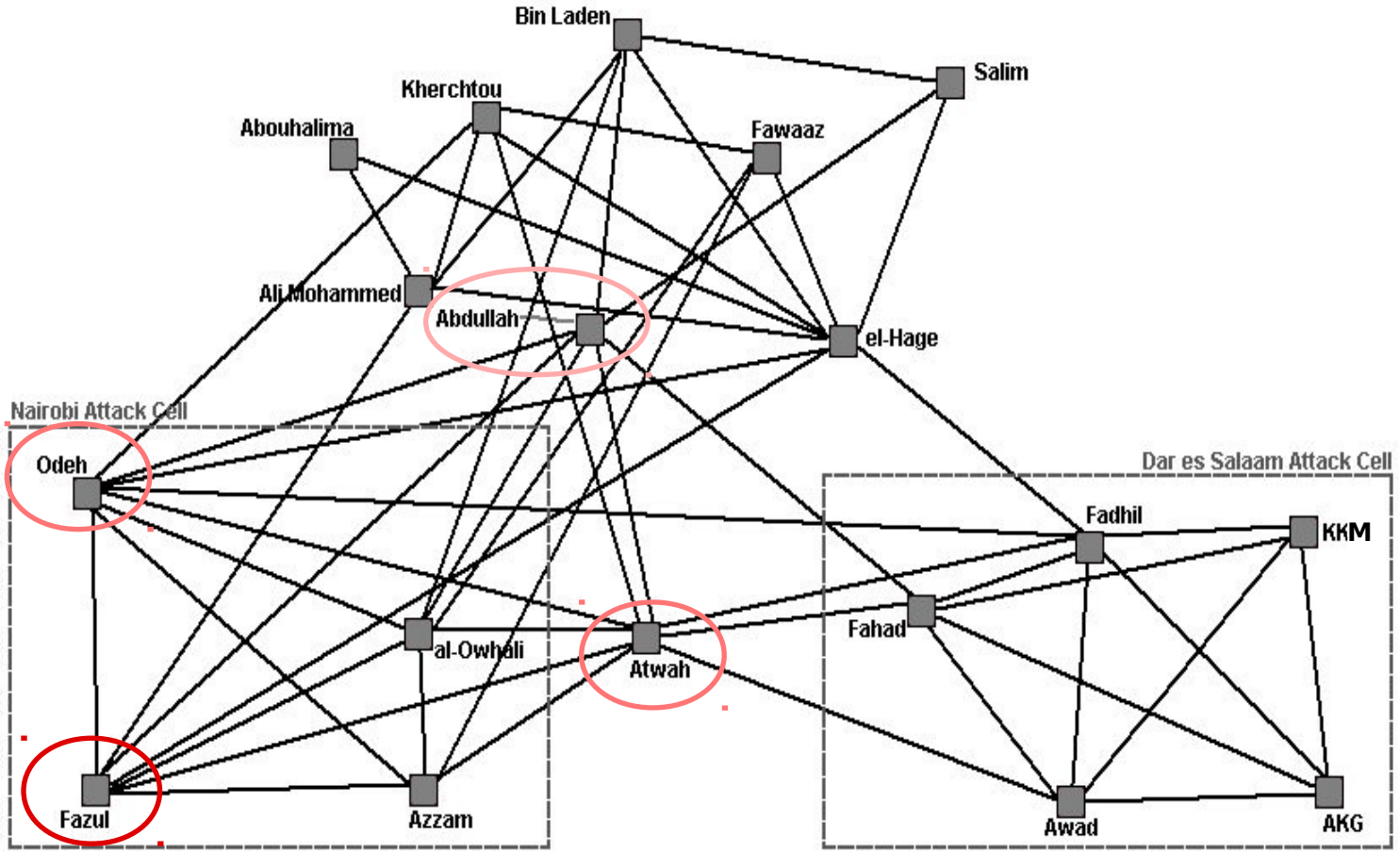
- **<u>Model Input</u>: A network of nodes and the connections between them.**

- **<u>Model Output</u>: The set of nodes critical to the structure of the network**

- **<u>The Solution</u>: The disruption target set KP of nodes**
  - **The disruption effect of KP maximizes distance between all remaining nodes**

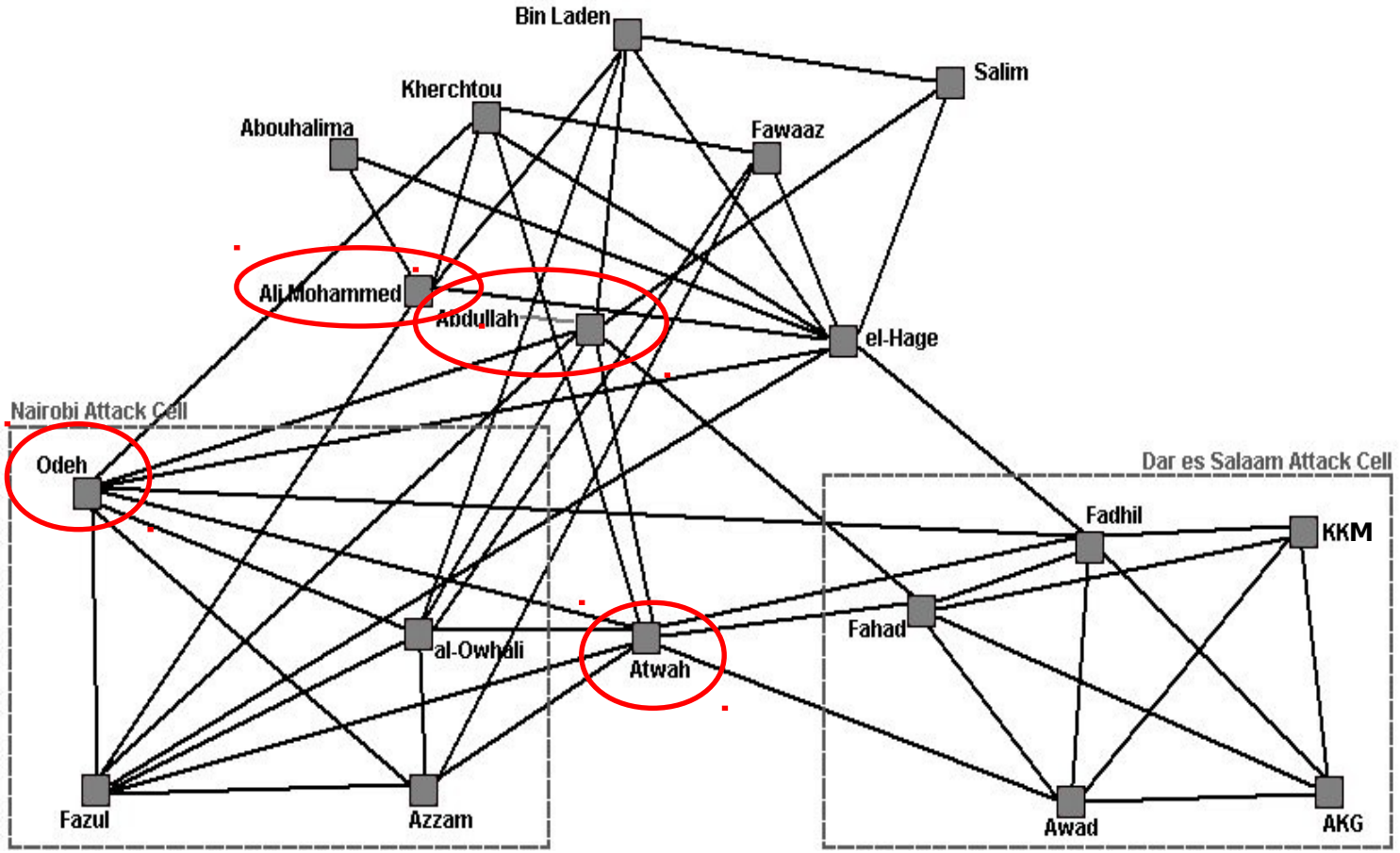
Previous Destabilization Preference

- **Preference for influence or removal**



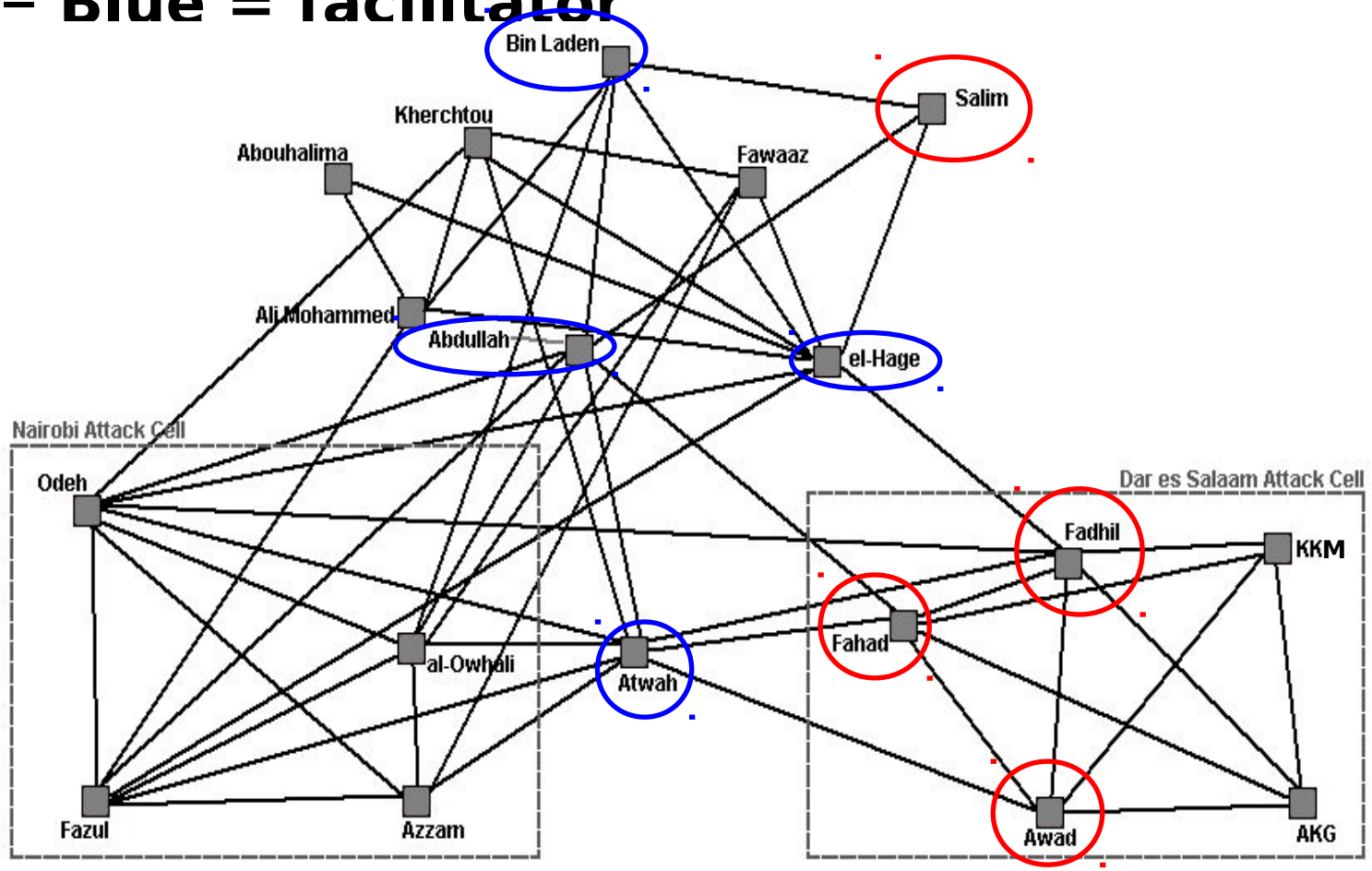
Application- Key player problem

- **Disrupting the connections for all members**



Application-Isolation Set Problem

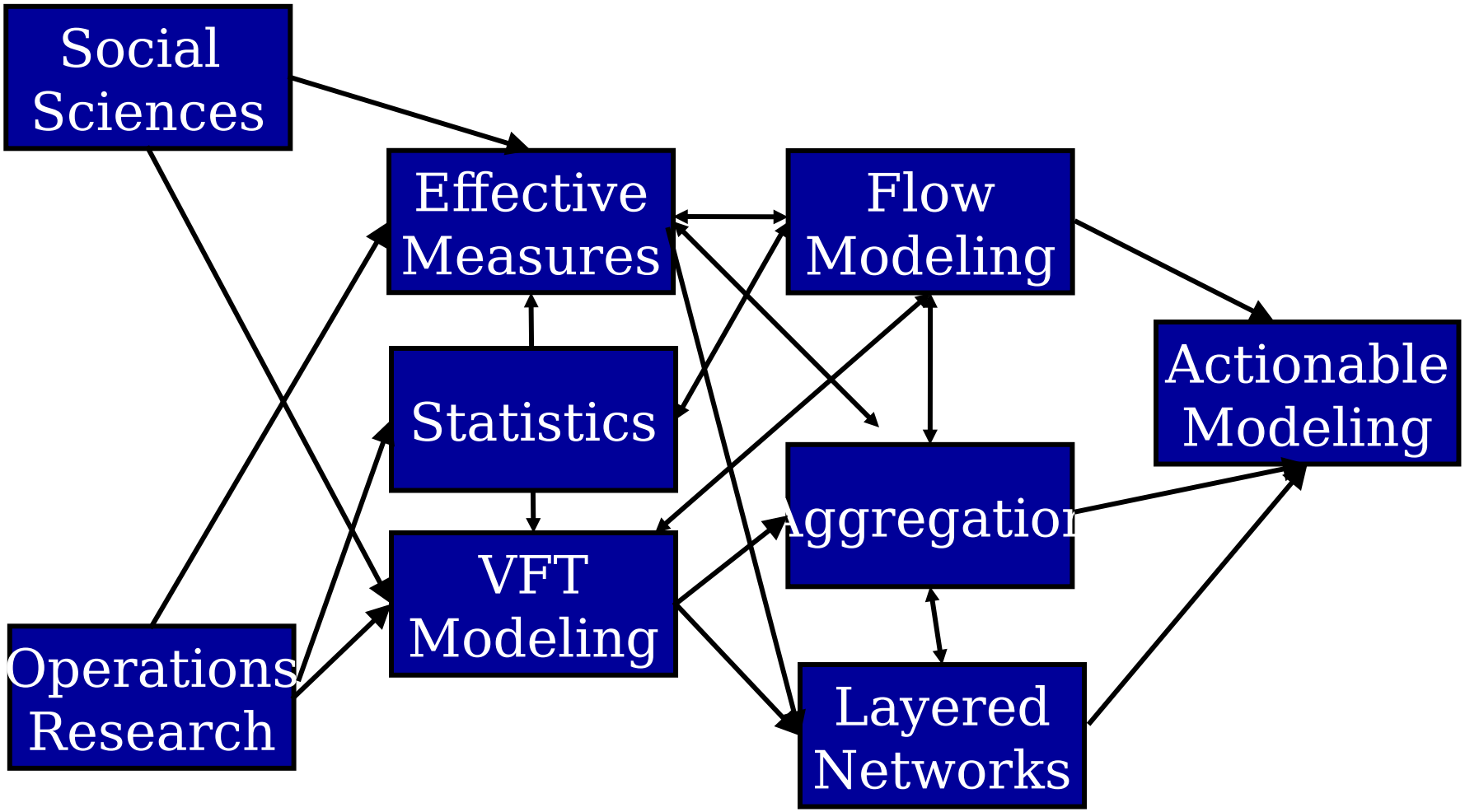
- **Disrupting the operation facilitators**
  - **Blue = facilitator**



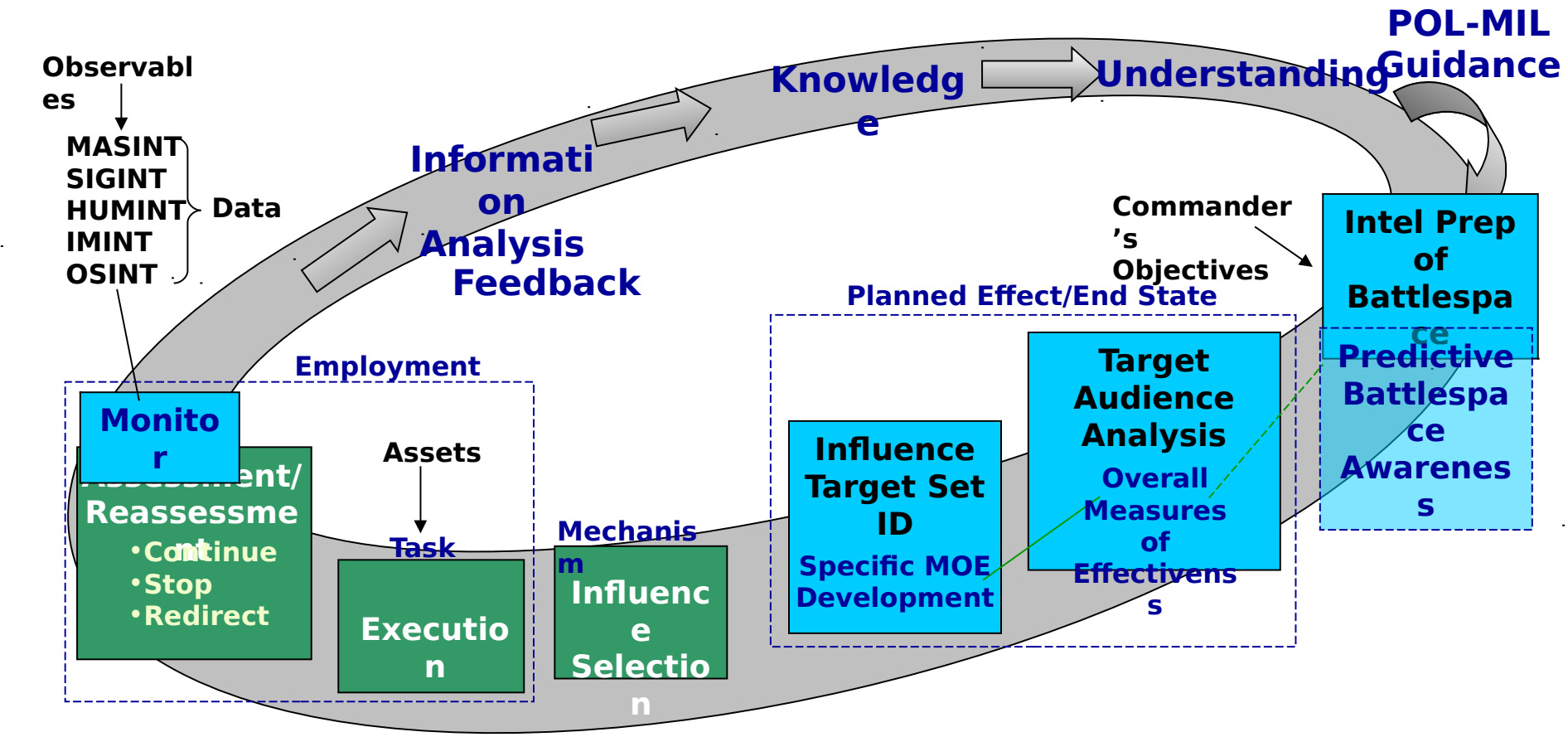
Summary

- The take away
- Isolation Set Problem
  - Proof of Linear Relaxation
  - New models of real world limitations
  - MATLAB and C++ code to solve and display ISPc and ISP
- Key Player Problem
  - Proposed previously unknown deterministic methods
  - Introduction of new KPP3 model
  - Proposed heuristic method
  - MATLAB and C++ code to solve and display KPP1 and KPP3
  - Statistical testing to demonstrate KPP3H is an effective procedure

Overview of Plan



Influence Operations Chain



Adapted from SRA, Intl. ,AFRL/HE, and Jannarone

Questions?